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Evaluation of the effect of microalloying on cleavage of monocrystalline NiAl using a miniaturized disk-bend test

Summary of Research for the period

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Alan J. Ardell

Principal Investigator

Department of Materials Science and Engineering

University of California

Los Angeles, CA 90095-1595

National Aeronautics and Space Administration

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Lewis Research Center, MS 49-3

Cleveland, OH 44135

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Summary of Research

It was originally proposed to investigate the effect of microalloying on the ductility of monocrystalline NiAl. The idea was to deposit selected elements on oriented crystals of NiAl using magnetron sputtering, followed by annealing at high temperatures to produce the doped specimens. The project was terminated before that stage of the research was reached, but useful results needed for that study were obtained during the lifetime of the program. Those results are described in this report.

A previously-developed miniaturized disk-bend test (MDBT) [1,2] was used to study the mechanical properties of two NiAl single crystals of different impurity levels, a commercial purity alloy (CP) and a high purity alloy (HP). These alloys were obtained from GE Aircraft, Cincinnati, courtesy of Dr. Ram Darolia. Two orientations of the disks (3 mm in diameter and up to ~400 μm thick) were selected for study: a "hard" orientation, [100], and a "soft" orientation, [110]. The validity of using the MDBT for an anisotropic material such as NiAl was investigated, and using data from our own tests, previously reported data, and cross-sectional optical microscopy, it was concluded that the yield stresses of disks in in the soft orientation could be measured accurately using an equation valid for isotropic materials. The specimens in the hard orientation deformed by punching-out of the center section rather than bending.

The effect of heat treatment on the room-temperature mechanical behavior of soft-oriented NiAl was also investigated. The annealing treatments affected the yield stress more strongly than either ductility or fracture load. The yield stresses of both of the as-received alloys increased significantly after annealing at 1300 °C followed by furnace cooling. Subsequent annealing at 400 °C for 2 h resulted in a reduction of the yield stress. This behavior is attributed to the role of excess vacancies retained during cooling, which annealed out at the lower temperature. The mean values of the yield strength also tended to decrease with increasing cooling rate from 400 °C, but the effect was small. A substantial increase in the yield stress of the CP alloy was found on prolonged aging at 400 °C, whereas the yield stress of the HP alloy was unaffected. This behavior is attributed to the precipitation of very small particles or solute atom clusters in the CP alloy. The ductility of the CP alloy, and the thickness-compensated fracture loads of both alloys were relatively insensitive to the heat treatments.

Experiments were conducted on disk-shaped specimens of monocrystalline NiAl in (011) orientation and containing Vickers indentations oriented with corners parallel to both [100] and [01$\bar{1}$]. We have also investigated the effect of purity by performing comparable experiments on alloys of commercial and high purity. The indentation was then made at the center of the disk (to within ±10 μm) using a 5 kg indentation load. This load was selected because preliminary tests performed using lower loads failed to produce cracks emanating from the corners of the indentation. Comparison of the fiducial markings on the disks indicated that the initial cracks in both alloys were parallel to the (100) trace. Electron channeling patterns and evidence from optical microscopy indicate that the macroscopic fracture plane is (100). In fact, these {100}-type fractures resemble the fracture facets in the [001]-oriented specimens of Takasugi et al. [3].

The results of this investigation showed that {110} is not the preferred cleavage plane in NiAl, contrary to what has been reported in the literature. Instead, crack initiation occurs preferentially on planes close in orientation to {100}. Fractography of the {100} fracture surface shows that {100} is itself not a cleavage plane in NiAl; this finding agrees with the results of prior work. However, it is entirely possible that transient cleavage planes of the type {511} and {711} are responsible for the average {100} orientation observed, thereby accounting for its multi-faceted nature. Cleavage on {110}, which does indeed occur afterwards, produces a relatively clean, featureless fracture surface. The similarities of the fracture surfaces indicate that, apart from the larger plasticity of the HP alloy, cleavage in both alloys is not strongly affected by the differences in their impurity concentrations.

References

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Personnel

In addition to the Principal Investigator, one graduate student, Ha K. DeMarco, received financial support from the grant. She received her M.S. degree in 1995.